The Isotopic Composition of Anomalous and Galactic Cosmic Rays from SAMPEX

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Abstract

New measurements of the anomalous cosmic ray (ACR) isotopic composition are presented, using data from the Mass Spectrometer Telescope (MAST) on *SAMPEX*. At high invariant latitudes or in interplanetary space, ACR isotopic composition measurements require correction for contamination from galactic cosmic rays (GCRs); however, at lower latitudes singly-charged ACRs can penetrate the Earth's magnetic field while fully stripped GCRs of similar energies are excluded, allowing us to study a pure ACR sample. Preliminary values for ACRs obtained using this geomagnetic filter approach are: $^{15}\mathrm{N/N} < 0.032$, $^{18}\mathrm{O}/^{16}\mathrm{O} < 0.0057$, and $^{22}\mathrm{Ne}/^{20}\mathrm{Ne} = 0.087(+0.137, -0.026)$. We compare our values with those found by previous investigators and with those measured in other samples of solar and galactic material.

1 Introduction and Data Analysis

The Mass Spectrometer Telescope (MAST) [1] measures the elemental and isotopic composition of nuclei from He to Ni using the dE/dx vs residual energy technique over an energy interval which varies with species, being $\sim 15 - 150$ MeV/n for CNO. In this interval, the dominant contribution to the quiet time flux varies from the anomalous cosmic ray (ACR) component at low energies to the galactic cosmic ray (GCR) component at high energies for the elements N, O, and Ne. If the ACR component is an accelerated sample of the local interstellar medium (ISM), the secondary isotopes produced in GCRs by nuclear fragmentation during galactic propagation should be absent in ACRs, resulting in an interplanetary composition nearly identical to that of the ACR source material, with only small modifications due to differing acceleration efficiencies for different isotopes. If the ACR isotopic composition could be determined, it would allow important comparisons between solar, GCR source, and local ISM nucleosynthetic histories.

For this work, we consider N, O, and Ne events observed by MAST during solar quiet times in the 2 year period between the launch of *SAMPEX* in July 1992 and July of 1994. For the first part of the analysis, we restrict our attention to events which occurred above 65° in invariant latitude, to eliminate the geomagnetically trapped ACR population [2], and study the energy dependence of the isotopic composition, following the approach of Mewaldt et al. [3]. Mass histograms for these elements in two energy intervals are shown in Figure 1.

Dramatic changes in the isotopic composition with energy are clearly seen. Notice that in each case, some events of the heavier isotope are still present even at the lowest energies MAST can reach. Mass resolution is presently $\sigma_M \sim 0.2$ amu at O, with small non-Gaussian tails. All parameters involved in the mass calculation, such as energy calibrations and detector thickness maps, are currently undergoing extensive review and modification, and the resolution or tails may improve once the

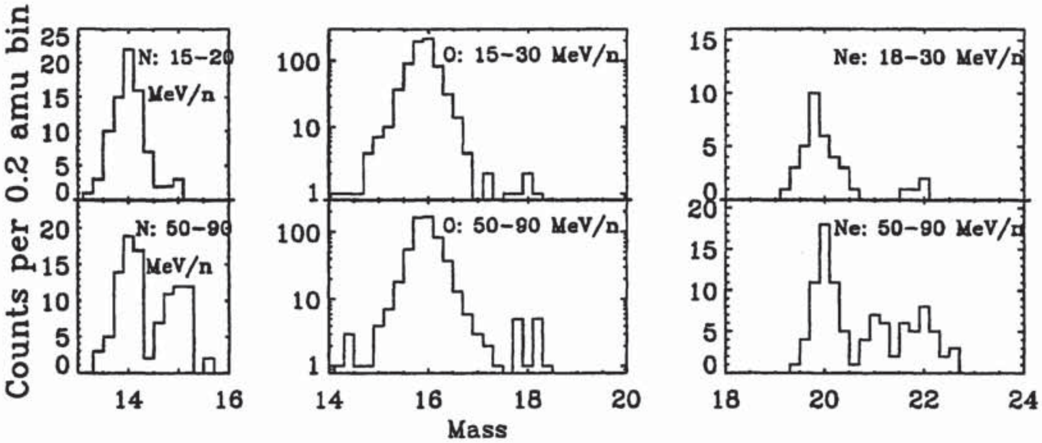

Figure 1 – Selected mass histograms for quiet time N, O (note logarithmic scale), and Ne above 65° invariant latitude, at low energies (top) and higher energies (bottom).

revisions are in place. In the meantime, we determine relative abundances by simply counting the events in each peak, allowing additional uncertainty over that based on Poisson statistics in cases where peak overlap appears likely.

2 Results and Discussion

The resulting abundances are plotted in figure 2 as a function of energy, along with those previously measured. Curves shown in the figure are very preliminary estimates of the expected energy dependence of the isotopic composition, given the ACR abundance ratio indicated on each curve. These curves represent a weighted average of the GCR composition (taken to be independent of energy) and each assumed ACR composition, with energy–dependent weighting factors obtained from power law fits to preliminary ACR and GCR spectra. The shape and location of the transition region in each curve is highly sensitive to the spectra, and therefore varies considerably during the solar cycle. Thus, the curves shown are in general only approximately valid for comparison with the other low energy data measured at different times.

The plotted curves serve to illustrate several points. First, assuming a reasonable range of values for the ACR isotopic composition, a strong energy dependence is in fact expected, much as is observed. Secondly, it is important to measure the composition at as low an energy as possible, as above energies of a few 10s of MeV/n, the observed isotopic composition is largely insensitive to that of the ACRs. Note, for example, that an order of magnitude change in the ACR ^{15}N/N ratio results in an expected change of only $\sim$ 50% in the measured ^{15}N/N value at 20 MeV/n. Finally, even at the lowest energies measured by MAST, contamination by low energy GCRs provides a significant, if not dominant, fraction of the measured heavy isotope events.

Based on the direction of the curves, it is clear that a definite, if crude, upper limit on the ACR isotopic composition can be obtained from the lowest energy point for each element, independent of calculated expected values. Our measurements provide a significant improvement on such a limit for ^{18}O/^{16}O and ^{15}N/N, being factors of $\sim 2-3$ lower than previous measurements [3], while for Ne, we confirm that the ACR ^{22}Ne/^{20}Ne ratio is significantly less than that of the GCR source [12].

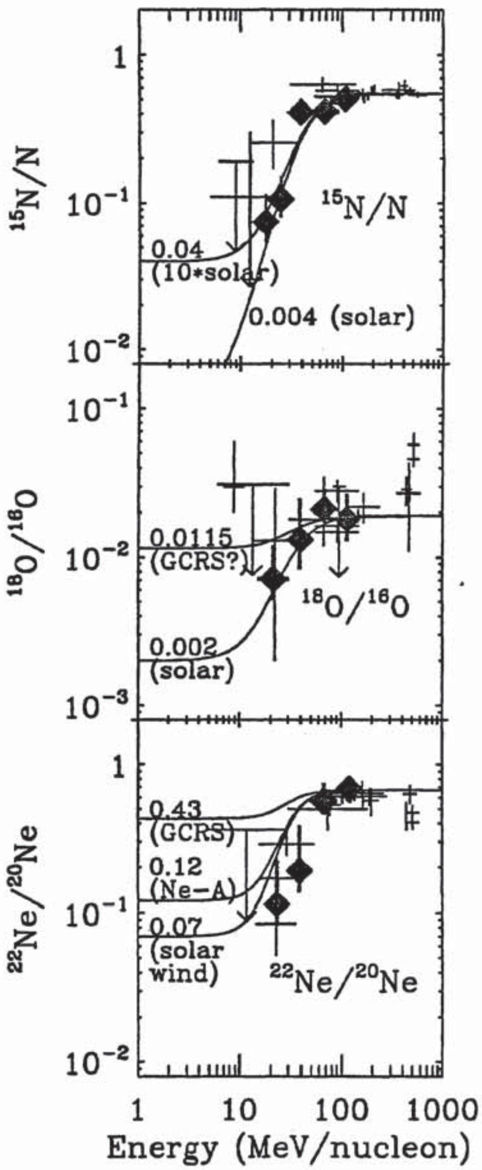

Figure 2 - Observed isotopic composition for N, O, and Ne from MAST (filled diamonds) vs energy, compared to previous measurements (pluses) (from compilation by Mewaldt et al. [3] and from [4-12]), and expected values (curves; see text).

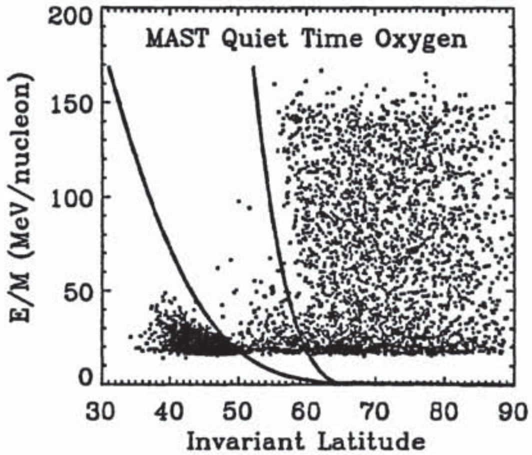

Figure 3 - Energy per nucleon vs invariant latitude for MAST quiet time O, showing cuts used to select a pure ACR sample at mid-latitudes. Trapped ACRs make up the dense concentration at low latitudes, while GCRs are restricted to the higher latitudes.

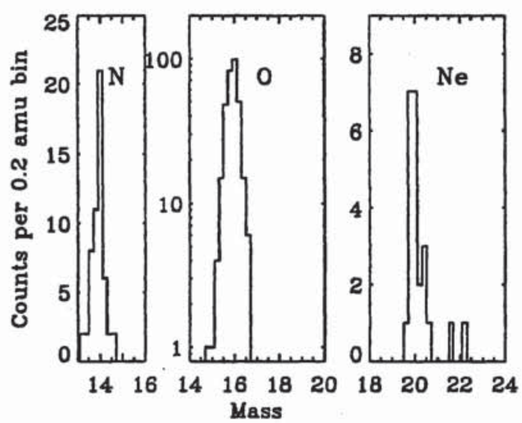

Figure 4 - Mass histograms for "pure" ACR N, O, and Ne using the geomagnetic filter.

In the polar Earth orbit of *SAMPEX*, it is possible to use the geomagnetic field as a rigidity filter [1, 13]. In Figure 3 the energy per nucleon vs invariant latitude is plotted for quiet time O seen by MAST. At high latitudes, the GCRs extend to high energies, with an enhancement at low energies due to ACRs also visible. In the mid–latitude interval, it is clear that GCRs are excluded as they fall below the local geomagnetic cutoff rigidity, while singly–charged ACRs have a higher rigidity than fully stripped GCRs at the same energy per nucleon, and penetrate to these latitudes. At lower latitudes are the trapped ACRs [2], which are not considered here. By selecting only events between the two curves in Figure 3, which correspond to the product of the adiabaticity parameter ϵ and ionic charge Q of $\epsilon Q = 0.9$ [14] at the low end and an empirically derived cutoff for fully stripped particles at the high end [15, 16], (adjusted down 10% in rigidity to reduce potential GCR contamination from cutoff suppression during geomagnetically active periods), we obtain a pure sample of ACR O. Similar cuts were made for N and Ne, and the isotopic composition of this sample was examined.

The results, shown in Figure 4, are quite striking. In contrast to the low energy polar measurements (Figure 1), not a single ^{15}N or ^{18}O event appears in the pure ACR sample. From these histograms, we find preliminary values at the 84% confidence level of the arriving ACR isotopic abundances to be: $^{15}\mathrm{N}/\mathrm{N} < 0.032$, $^{18}\mathrm{O}/^{16}\mathrm{O} < 0.0057$, and $^{22}\mathrm{Ne}/^{20}\mathrm{Ne} = 0.087^{+0.137}_{-0.026}$. This is within a factor of 8 of the solar value for N, and less than a factor of 3 greater than the solar value for O, while the Ne measurement spans the values found in the solar wind, solar flares, and meteorites. At present, the GCR source $^{18}\mathrm{O}/^{16}\mathrm{O}$ ratio is unclear [5, 6, 9], however the ACR ^{18}O abundance appears to be lower than some of the higher reported values for the GCR source [9], just as is the case for ^{22}Ne. This may suggest that either the GCR source includes significant contributions from sources other than the ISM (such as material from Wolf–Rayet stars, for example), or that the very local ISM is atypical of that in the larger volume sampled by GCRs. As MAST continues to gather data under solar minimum conditions, we hope to obtain better ACR composition measurements with improved statistics.

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